Continuing Influence of Shell Effects in the Nuclear Quasi-Continuum

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- Nuclei polarize in the presence of an external electric and magnetic field.
- Polarizability (α) is driven by dynamics of giant dipole resonance (GDR).

$$\alpha = \frac{e^2 R^2 A}{40 a_{sym}} = 2.25 \times 10^{-3} A^{5/3} \text{ fm}^3$$

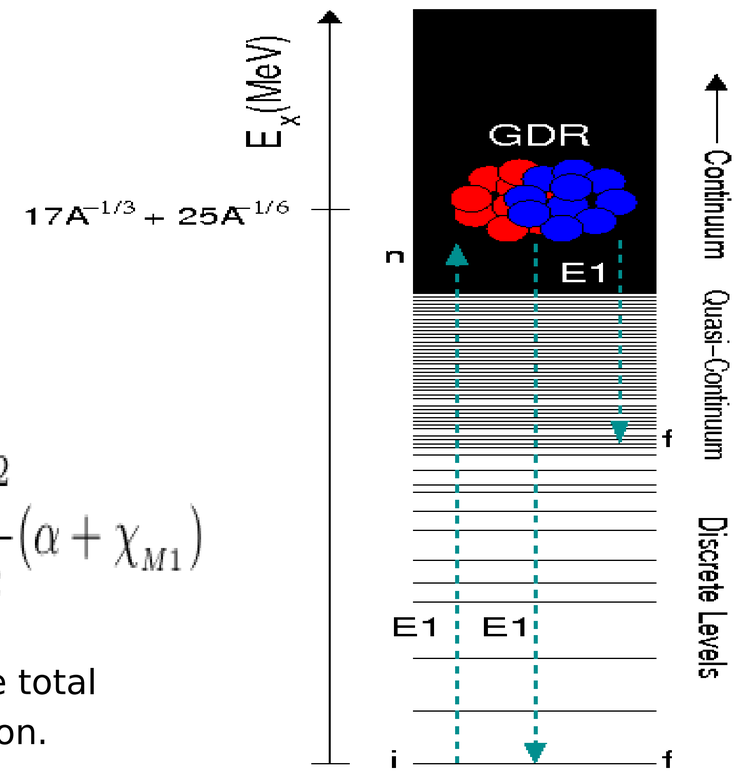
Alternatively,

$$\alpha = 2e^2 \sum_n \frac{\langle i \| \hat{E1} \| n \rangle \langle n \| \hat{E1} \| i \rangle}{E_\gamma} = \frac{\hbar c}{2\pi^2} \sigma_{-2}$$

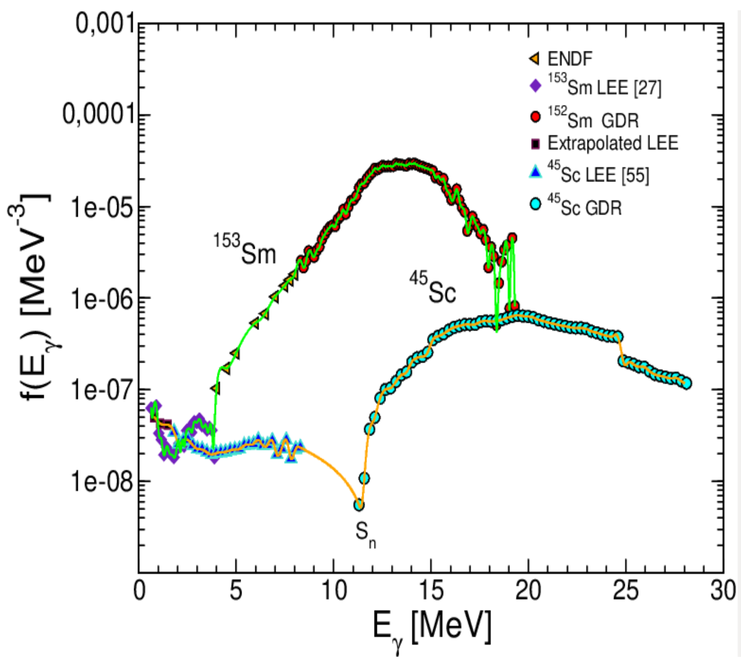
with,

$$\sigma_{-2} = \int \frac{\sigma(E_\gamma)}{E_\gamma^2} dE_\gamma = \frac{2\pi^2}{\hbar c} (\alpha + \chi_{M1})$$

being the σ_{-2} moment of the total photo-absorption cross section.

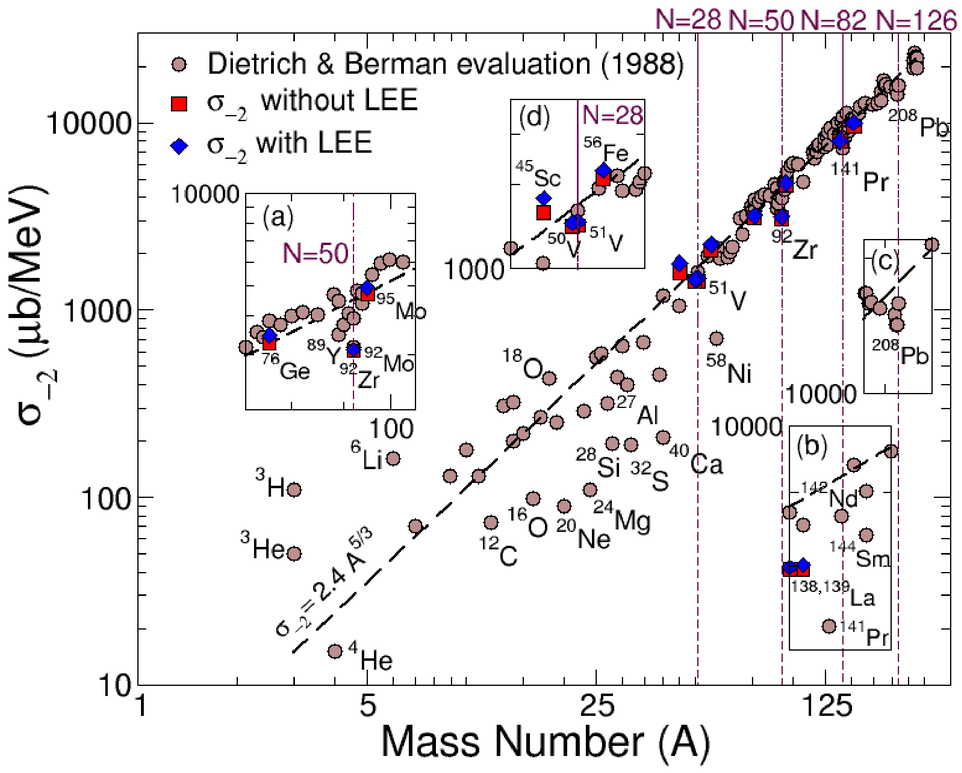


- Combining cross-section contributions from the GDR and LEE (assuming Brink-Axel hypothesis) :
- The LEE (Low-energy enhancement) of photon strength function is observed as an up-bend at low energies on nuclei in A ≈ 50 and 90 mass region - which are not well deformed.
- LEE origin remains unknown (M1 or E1). Shell model calculations support M1 nature of the LEE for A ≈ 50 (K. Sieja PRL 2017).
- LEE is sensitive to changes of polarizability in the quasi-continuum, yielding enhanced polarizability.
- The LEE could change abundances of heavy elements in the r-process (one site finally found as neutron stars mergers) by two orders of magnitude!



Nucleus	$E_{\gamma(max)}$ (MeV)	σ_{-2}(total) (μb/MeV)	σ_{-2} (LEE)	κ (LEE)
$^{45}_{21}$Sc*	28.1	1780(89)	10.9%	1.30(7)
$^{50}_{23}$V	27.8	1458(74)	2.9%	0.89(5)
$^{51}_{23}$V	27.8	1472(75)	3.3%	0.87(5)
$^{56}_{26}$Fe*	40.0	2231(112)	6.3%	1.13(6)
$^{76}_{32}$Ge	26.5	3189(163)	2.7%	0.97(5)
$^{92}_{40}$Zr	27.8	3131(156)	1.1%	0.70(3)
$^{95}_{42}$Mo	27.8	4743(236)	1.7%	1.00(5)
$^{138}_{57}$La	24.3	7983(414)	0.4%	0.90(5)
$^{139}_{57}$La	24.3	8015(411)	0.7%	0.90(4)
$^{153}_{62}$Sm	20.0	9999(467)	2.7%	0.95(5)

Table 1: LEE contribution to σ_{-2} and to the nuclear polarizability parameter, k. Data have been extracted from EXFOR and ENSDF.



- Sudden drops of σ(−2) (and κ) values are apparent for the N = 50, 82 and 126 isotones in the insets (a),(b) and (c). Implying continuation of shell effects
- The polarizability parameter (κ) represents deviations from the actual GDR effects.

$$\sigma_{-2} = 2.4 \kappa A^{5/3} \mu\text{b/MeV}$$

- The enhancement of polarizability in medium-mass nuclei appears to be structure dependent.
- Table 1 shows that the LEE has a substantial contribution to σ(−2) values in medium-mass nuclei (45-Sc & 56-Fe) away from the N = 28 shell closure, being largest for 45-Sc with 11% increase and negligible in heavy nuclei.
- Above nucleon thresholds the σ(total) in lower part of the GDR is governed by the statistical competition between σ(γ, p) and σ(γ, n), particularly dominated by σ(γ, p) in less bound light nuclei.
- The LEE may provide an alternative probe to investigate the rise or absence of magic shell closures in the quasi-continuum.
- Further work is clearly needed, e.g., using the powerful combination of large-volume $LaBr_3$ and clover detectors given by the GAMKA Spectrometer.

- Drops of σ(−2) values (κ < 1) for several nuclei with, or close to, neutron magic numbers N = 28, 50, 82 and 126, suggest that the shell model remains valid at high excitation energies, from thequasi-continuum to the GDR region.
- The empirical evidence for shell effects suggests that the Brink-Axel hypothesis allows for structural changes and is, therefore, more universal than originally expected.
- Finally, we confirm the induction of permanent magnetic dipole moments or paramagnetism in the quasi-continuum region, in agreement with previous SM calculations and IPM predictions of an enhanced paramagnetism for the ground states of nuclei with large occupation number of the shells determining the magnetic properties.

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